

# **HYDRODYNAMICS OF INVERSE LIQUID FLUIDISED BED**

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Of  
**Bachelor of Technology (Chemical Engineering)**

**By**  
**Bajrang Lal Bagria**  
**Roll No. 107CH026**

**UNDER THE GUIDANCE OF**

Prof. Basudeb Munshi



**DEPARTMENT OF CHEMICAL ENGINEERING**  
**NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA**  
**ORISSA-769008, INDIA**  
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Department of Chemical Engineering  
National Institute of Technology-Rourkela

## CERTIFICATE

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This is to certify that the thesis entitled “HYDRODYNAMICS OF INVERSE LIQUID FLUIDIZED BED” submitted by Bajrang Lal Bagria to National Institute of Technology, Rourkela is a record of bonafide project work under my supervision and is worthy for the partial fulfillment of the Degree of ‘Bachelor of Technology’ (Chemical Engineering) of the Institute. The candidate has fulfilled all prescribed requirements and the thesis, which is based on candidate’s own work, has not been submitted elsewhere.

Supervisor

Prof. Basudeb Munshi

Department of Chemical Engineering

National Institute of Technology

Rourkela - 769008

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Bajrang Lal Bagria

107CH026

Department of Chemical Engineering  
National Institute of Technology

# ABSTRACT

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Poly Propylene Particles of size 6.1mm and density 0.93kg/liter were fluidized by a downward flow of water in an inverse fluidization mode. A set of experiments were conducted with the set-up for varied flow rates of inlet stream of water, each for the different number of particles. The hydrodynamic characteristics of beds of Poly Propylene particles were studied by measuring the pressure drop, bed expansion and minimum fluidization velocity as a function of flow rate and superficial velocity respectively.

Among the advantages of the process are reduced energy consumption, less bubbling, high rate of heat and mass transfer and better mixing as observed from the experiment. It is found that minimum fluidization velocity doesn't depend on the initial bed height. Pressure differences were measured at every 10cm height throughout the column. The inverse fluidized beds have many applications in the variety of fields.

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## INTRODUCTION

Fluidization is a technique through which fine solid particles behaves like a fluid through contact with liquid or gas or both. Under the fluidized state, the fluidized state, gravitational pull force on solid particles is offset by the fluid drag force. In fluidized condition particles remain in a semi-suspended condition.

The term 'fluidization' is usually associated with two or three phase systems, in which solid particles are fluidized by a liquid or gas stream flowing in the direction opposite to that of gravity. In these classical fluidized bed systems, the solid particles have a higher density than the fluid. Fluidization where the liquid is a continuous phase is commonly conducted with an upward flow of the liquid in liquid-solid systems or with an upward co-current flow of the gas and the liquid in gas-liquid-solid systems. Under these fluidization conditions, a bed of particles with a density higher than that of the liquid is fluidized with an upward flow of the liquid counter to the net gravitational force of the particles.

### 1.1 INVERSE FLUIDIZATION:

When the density of the particles is smaller than that of the liquid and the liquid is the continuous phase, Fluidization can be achieved by down flow of liquid, it called Inverse Fluidization. Considering a bed of solid particles floating on a fluid surface, when a liquid or a gas is passed at a very low velocity down through the bed of particles, the particles start to move and there is a pressure drop. Increasing the fluid velocity steadily, the pressure drop and the drag on the individual particles increases and eventually the particles move more vigorously and get suspended in the fluid. The particles float or sink depending on their density relative to the fluid/suspension. If the density of solid particles and continuous liquid

phase is almost same then fluidization is only achieved by counter-current flow of gas and this type of fluidization is called solid-liquid-gas inverse fluidized bed.

## 1.2 CLASSIFICATION:

If we only take into consideration the processes where the liquid is the continuous phase, two configurations are possible. The first case generally involves particles with a density higher than that of the liquid. It is known as mode E-I-a in Fan's (1989) classification. This kind of a reactor is widely used at the industrial scale, and well described in the literature (Wild et al., 1984; Muroyama and Fan, 1985). In the second case, solid particles may have a density lower than the liquid: this kind of reactor is commonly named inverse three-phase fluidized bed (referred as mode E-II-a by Fan), or inverse three-phase turbulent bed where the fluidization is only ensured by the gas flow (Comte et al., 1997).

## 1.3 OBJECTIVE:

To study the hydrodynamics that include the minimum fluidization velocity, pressure drop for different heights throughout the column and the bed expansion of inverse liquid fluidization.

Experimentally find the pressure drop variation and bed expansion for different heights of the column, with liquid flow rate.

## Chapter-2

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### LITERATURE REVIEW

Fan, Muroyama, & Chern (1982) were the first to study the hydrodynamic characteristics of inverse fluidized bed using low density particles of different diameter and density. They proposed correlations to predict bed expansion and gas holdup.

The use of fluidized bed equipment in Industrial applications is gaining importance, with respect to the food and the pharmaceutical industry and also in petroleum refining.

The main reasons for the success is the ability of fluidized bed to perform a number of unit operations (mixing, drying, coating, granulating, mass transfer, heat transfer, separation, leaching)

With the development of fluidized bed, coal combustion and the recent interest in the use of fluidized beds for waste utilization and for dry solids separation, the potential applications of multi-component fluidized beds are on the rise. It is because, the fluidized particles though uniform in size at beginning, may change due to the attrition, coalescence and chemical reaction, thereby affecting the quality of fluidization .therefore proper characterization of the bed dynamics for the binary and the multi-component mixtures in gas solid systems is an important pre-requisite for their effective utilization, where the combination of particle size, density and shape influence fluidization behavior.

## **2.1 ADVANTAGES OF INVERSE FLUIDIZATION:**

Inverse fluidization has got many advantages over the existing technique of fluidization. A few of them are as follows;

### **2.1.1 Low energy consumption**

The inverse fluidization is achieved by a stream of fluid falling from the top and it is fluidizing in the direction of gravity against buoyancy. Hence not a very high velocity of inlet flow is required as in case of traditional fluidization. The minimum fluidization velocity is lower in this case. Also it takes lesser energy to pump a fluid to force the particles in this case. Hence viewing on a larger scale, at the industrial level, it can save a lot of energy. Such energy efficient processes are the need of today when energy crisis is at its peak.

### **2.1.2 High turbulence**

In inverse fluidization, a big advantage is the achievement of higher turbulence, which is aided by an initial collision of fluid inlet with the bed particles, leading to foaming. This higher turbulence is the key in better mixing, and more solid randomness which leads in higher heat transfer rates. Better the turbulence better will be mass transfer rates between solids and gases (3-phase inverse fluidization) which improve the performance of a chemical reactor.

### **2.1.3 Gas-solid contact in gas-liquid-solid inverse fluidization**

The traditional fluidization is inefficient for the gas solid cases of mass transfer or mixing and often many alternatives have to be used for the purpose. Inverse fluidization can promote contacting of solid and gas. A better mass transfer between gases and solids is expected in a 3-phase setup, improving the performance of the chemical reactor.

### **2.1.4 Erosion of vessel**

Inverse fluidization was seen to be achieved at a lower velocity of the inlet flow, comparative to traditional fluidization, it can be directly predicted that the equipment parts will definitely have a longer life in the case of inverse fluidization. This helps in reducing run-time costs to industries.

### **2.1.5 Economical**

The above four advantages show the efficiency of the process. Yet there are a few more ways how this process becomes economical. Firstly particles of the bed have to be lighter than the medium fluid. That does not mean particles of heavy materials cannot be used. A simple way is to use hollow particles, this gives a lighter particle and also the surface area available for a particle is more than that of a solid particle from a given amount of material. These hollow catalysts or bed particles can make the process further economical and useful for a wide range of fluid; especially lighter fluids with lesser viscosity.

In spite of the various advantages, the efficiency and quality of fluidization is adversely affected in cylindrical beds due to the particle size reduction results in entrainment, limitation of operating velocity in addition to other demerits like slugging, non-uniform fluidization associated with such beds.

## 2.2 APPLICATIONS OF INVERSE FLUIDIZED BEDS:

The various applications of inverse fluidized bed are:

1. An important application of liquid-solid fluidized beds has been developed recently in biotechnology, namely, immobilized biocatalyst bioreactors.
2. Inverse fluidization finds main application in environmental engineering for waste water treatment and in biochemical engineering.
3. Environmental engineering in biological reactors (Legile et al).
4. Efficient control of biofilm thickness and ease of re-fluidization in case of power failure. These significant advantages found many applications of inverse fluidized beds in biochemical processes like ferrous iron oxidation and aerobic and anaerobic biological wastewater treatment like treatment of wine distillery waste-water. (Garcia Calderon, Buffiere, Moletta, & Elemaleh, 1998)
5. Minimum carryover of coated microorganisms due to less solids attrition

## 2.3 DRAWBACKS OF FLUIDIZATION:

1. Pressure Drop: Due to distributor there is high pressure drop.
2. Particle Entrainment:

## 2.4 PREVIOUS STUDIES ON HYDRODYNAMICS OF LIQUID-SOLID

### INVERSE FLUIDIZATION:

- 1) Ulaganathan and Krishnaiah studied the hydrodynamic characteristics of two-phase inverse fluidized bed reactor with 12.5 to 20 mm diameter in a 75 mm column. They presented equations to predict 'minimum fluidization velocity' and fenning friction factor.
  - 2) Femin et al. studied the pressure drop and bed expansion in a two-phase inverse fluidization column with 6 mm Low Density Poly Ethylene particles and Poly Propylene particles.
  - 3) Nikov and Karamanev have reported mass transfer studies in liquid inverse fluidized bed reactor. They found that the mass transfer rate is independent of superficial velocity and particles and strongly depends on the density of the particles.
-

## **EXPERIMENT**

### **3.1 EXPERIMENTAL SETUP:**

A schematic diagram of the experiment setup is shown in fig1.

The column is transparent and made up of acrylic material with an outer diameter 10 cm and the wall thickness of 2mm. Height of column is 1.25m, with an inlet at the top and an outlet at the bottom. The flow of the fluid (water) through this opening was controlled by use of valves. Water pumped through rota meters by 0.5HP motor pump to the top of the column.

Equal spaced pressure tapping's were mounted on the column wall and were connected to manometers there are total of 13 pressure tapping's on wall of column. The distance between two conjugative tappings is 10cm.

The distributor was used at both openings of the column 1mm diameter and perforates are arranged in a triangular pitch. A motor driven reciprocating Pump is used to pump the water at the top of column. A distributor is used to assure the uniform flow of liquid into the column. Two rota meters are used in series to control the flow of liquid.



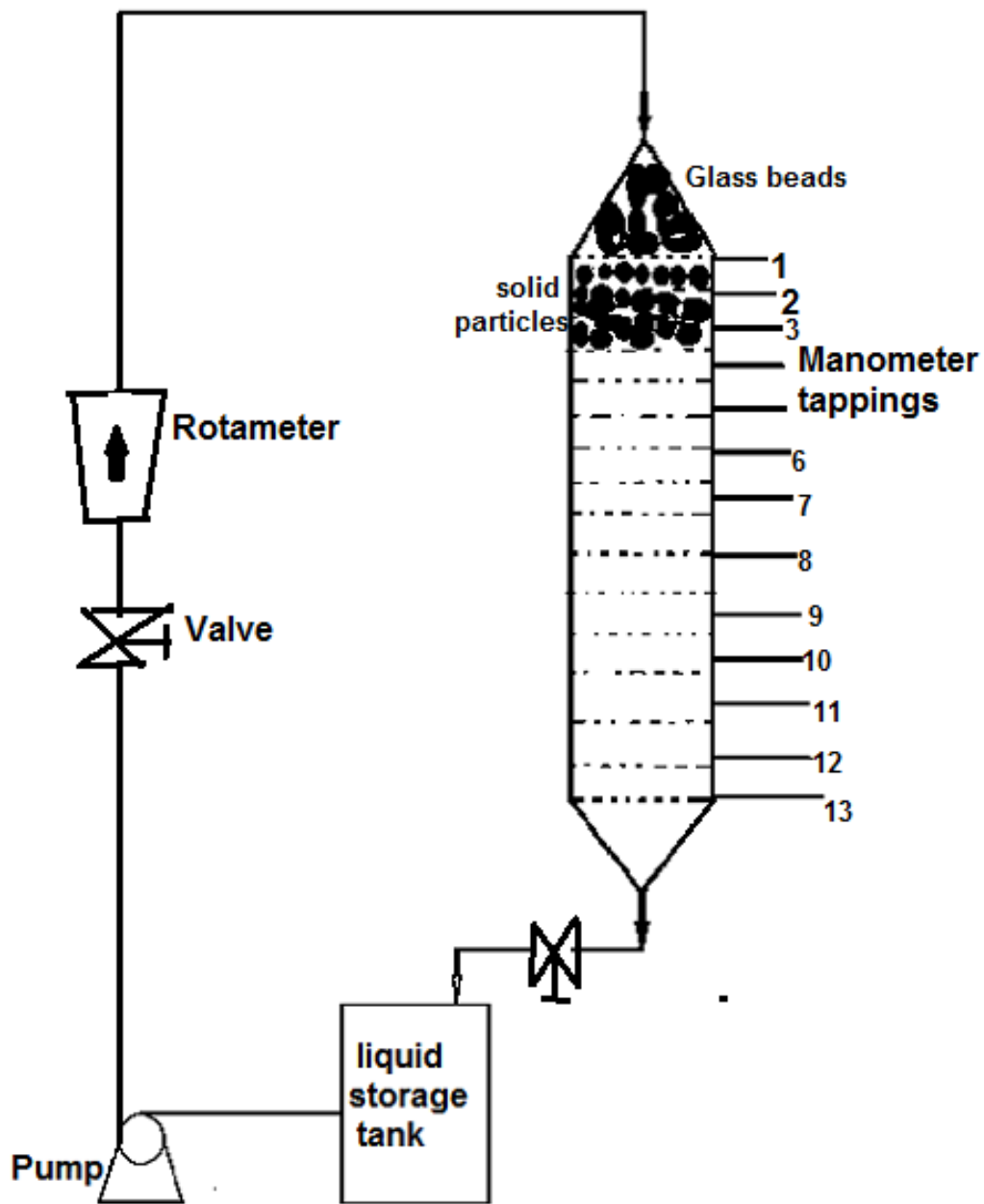


Fig. 1 Schematic diagram of experimental Set-up

### 3.2 Materials and methods:

A known quantity of solid particles Poly Propylene of density 0.93kg/litre and 6.1mm diameter is loaded in to the acrylic column. The pump was started and the column was filled with liquid. Prior to each experimental run the Poly Propylene particles were fully fluidized, subsequently the flow rate of liquid was gradually reduced until the solids rise up slowly to form a packed bed i.e. initial bed height. Then the flow rate was gradually increased and variation of bed height was observed. The minimum flow rate where the packed bed just starts moving is termed as initial fluidization velocity. The flow rate corresponding to the point where the bed height just starts changing was determined and referred as the minimum fluidization velocity. A U-tube manometer was used for the measurement of the pressure drop across the column. Carbon tetrachloride with density 1.59kg/litre was used as the manometric fluid.

### 3.3 EXPERIMENTAL PHENOMENA:

#### 3.3.1 FLOW REGIMES



Fig-2 ; Packed bed.

At low liquid velocities, the particles form a buoyant packed bed at the top of the column supported by the mesh. As the liquid velocity increased bottom layer of the particles just fluidizes and the rest will be in packed condition.

With further increase in velocity, higher and more particles at the bottom of the packed bed are fluidized and the bed height increases (Renganathan & Krishnaiah, 2003)



Fig-3 ; Bed under fluidized condition.

At one particular velocity the entire bed is in fluidized condition. The velocity corresponding to this condition is termed 'minimum fluidization velocity'. Though the entire bed is fluidized, the concentration of solids is not uniform along axis of bed. High concentration of solids is observed near the liquid distributor (Ibrahim et al, 1996) for further increase in velocity, the solid hold up becomes uniform throughout the bed. This velocity is termed 'uniform fluidization velocity'.





Fig-4; Condition for uniform fluidization.

# Chapter-4

## OBSERVATIONS, RESULTS AND DISCUSSIONS

### 4.1 OBSERVATIONS:

Table 1 ; Run No.1, Initial bed height was 0.13m.

S.No.	Flow rate( m <sup>3</sup> /h)	Min. fluidization velocity(m/sec.)	Bed height (m)
1	0.252	0.014	0.14

Table 2; run no-2, Initial bed height 0.12m.

S.No.	Flow Rate (m <sup>3</sup> /h)	Min. fluidization velocity (m/sec)	Bed height (m)
1	0.252	0.014	0.142

Table 3; Effect of superficial velocity on bed height.

Velocit y m/sec	0	0.006	0.008	0.010	0.012	0.014	0.016	0.018	0.020	0.022	0.024	0.026
Bed height (cm)	12	12.1	13	13.5	14.2	15	15.5	16.5	20	28.5	41	

Table 4; Pressure drop variation with flow rate at different heights of column.

Liquid flow rate m <sup>3</sup> /h	Manometer-1 Pascal	Manometer-2 Pascal	Manometer-3 Pascal	Manometer-4 Passcal
0.108	1296.5	265.5	1624.5	500
0.144	1390.2	312,4	1624.5	515.5
0.180	2264.9	594	1609	1015.3
0.216	2358.6	625	1593.3	1093.4
0.252	2296.14	578	1562	1031
0.270	2186.8	531	1546.4	1530.7
0.324	2327.4	546.7	1546.4	1624.5
0.360	2405.5	578	1500	1702.6
0.450	2249.3	515.5	1515	1359
0.540	2077.5	484.2	1500	1077.8
0.630	2108.7	546.7	1359	1140.3
0.720	2155.6	703	1343.3	1374.6
0.810	2171.2	750	1234	1452.6
0.900	2015	15.62	1171.5	1202.7
0.990	2140	234.3	1093.4	1390.2
1.080	1874.4	359.3	1046.5	968.44
1.26	1859	375	1031	921.6
1.39	1734	243.3	1015.3	968.4

## 4.2 RESULTS AND DISCUSSIONS:

### 4.2.1 Minimum Fluidization velocity;

1. The minimum fluidization velocity does not depend on the initial bed height.
2.  $U_{mf}$  depends upon the density of particles, for higher density particles  $U_{mf}$  will be low than the lower density particles. As the particle density decreases, the upward buoyancy force increases and a higher downward force (that is liquid flow rate) is required to reach the condition of onset of fluidization.

### 4.2.2 Bed Expansion;

1. Bed expansion characteristics in liquid-solid fluidization are an important parameter which helps in the design and scale-up of fluidised bed for an envisaged application.  
(R.J Femin Bendict et al).
2. The bed expands only if the flow rate is above the minimum fluidization velocity.
3. The bed with larger initial bed height expands faster than the less initial bed height.

It is observed from the figure-5 that the bed height remains unaffected (fixed) up to a certain liquid flow rates and there-after varies linearly with flow rates. And it is also observed by existed literature that bed height variation depends on solid densities. It is due to the fact that at a low flow rate the force due to the downward flow of liquids is less than the net buoyancy force of the particles acting in the opposite direction. Hence the particles remain as a packed bed attached to the top distributor plate. With further increase in flow rate, a condition (net upward force just equals to net downward force) is reached where the lowest layer of the particles just starts to get detached from the bed. The velocity corresponding to this flow rate is termed as minimum fluidization velocity ( $U_{mf}$ ) and the condition is referred as on-set of fluidization. With further increase in flow rate, more and more particles get detached from the



packed bed, bed height increases linearly as the downward force due to the liquid overcomes the upward buoyancy forces due to the low density particles.

The observed trend is similar to that of classical fluidization.

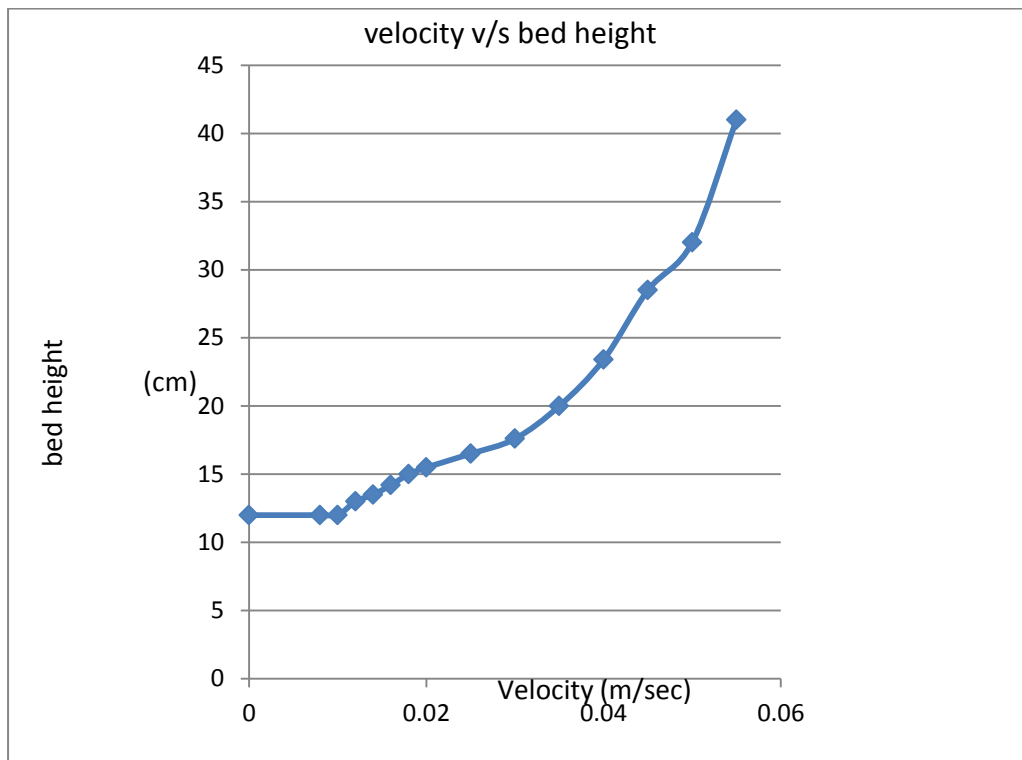


Fig-5, Variation of bed height with liquid flow rate for the system water- 6mm Poly Propylene Particles.

### **4.2.3 Pressure Drop;**

The determination of pressure drop in fluidized bed is a very important parameter for the efficient and economical operation of the reactor, since it facilitates us to determine friction factor i.e. energy loss and conditions of stable flow regimes of inverse fluidized bed reactor for the given operation.

In classical fluidization the pressure drop increases with increase in liquid flow rate till the condition of on-set of fluidization is reached which represents packed bed. On further increase the pressure drop remains almost constant as the resistance for the liquid decreases significantly, (R.J Femin Bendict et al).

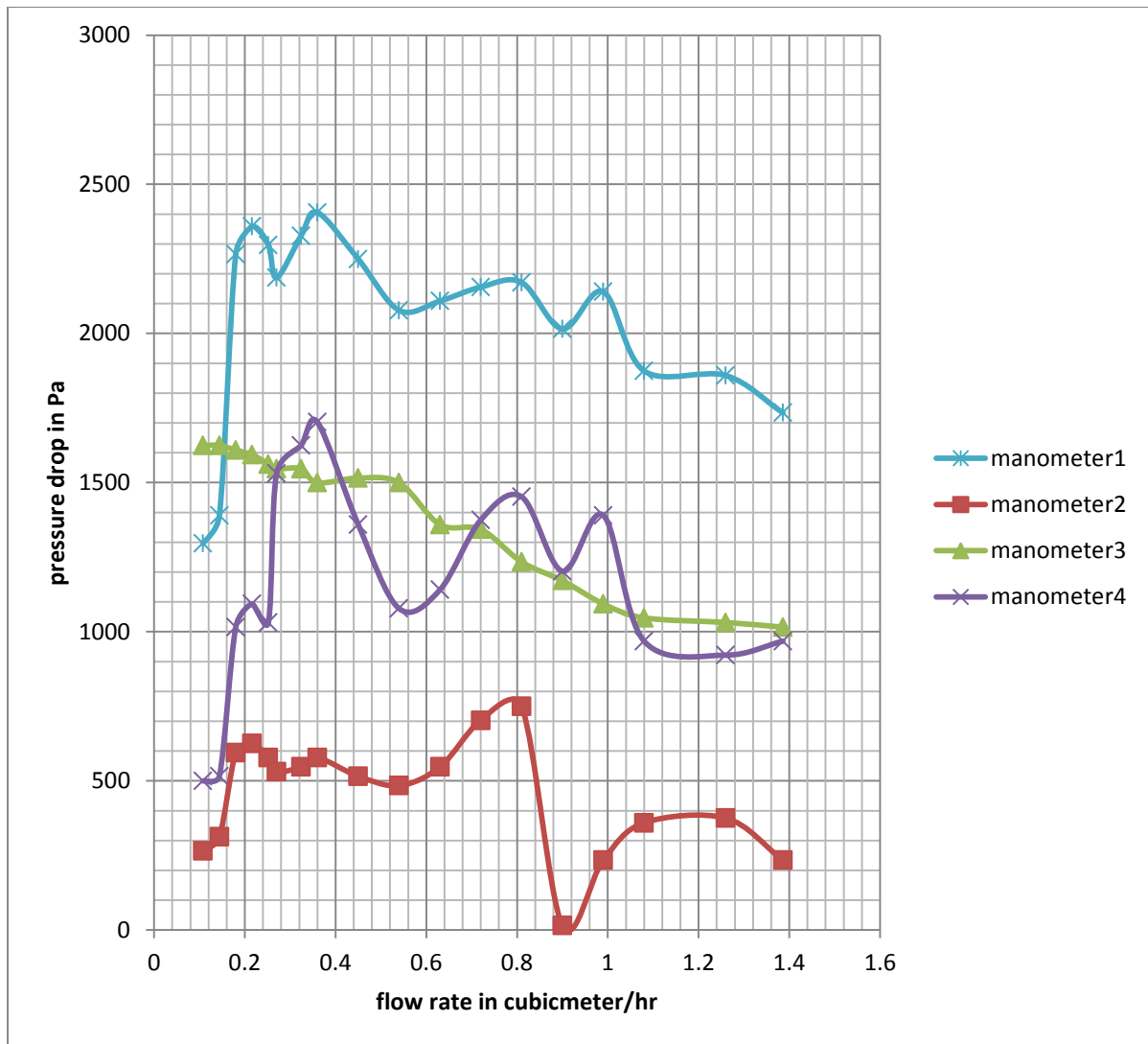


Fig-6, Variation of pressure drop between different tapplings with respect to liquid flow rate.

Manometer1 = The Pressure difference between 2<sup>nd</sup> and 3<sup>rd</sup> tapplings.

Manometer2 = The Pressure difference between 4<sup>th</sup> and 5<sup>th</sup> tapplings.

Manometer3 = The Pressure difference between 6<sup>th</sup> and 7<sup>th</sup> tapplings.

Manometer4 = The Pressure difference between 8<sup>th</sup> and 9<sup>th</sup> tapplings.

The numbers to the tapplings are according to fig-1

The graph 'flow rate v/s pressure drop' is plotted from the experimental data's. the graph obtained is not smooth that mean in the prediction of pressure drop there will be significant error. Observations from the graph are :-

1. Initially the bed lies between tapping 1<sup>st</sup> and 2<sup>nd</sup>, so there is the maximum pressure drop. As the flow rate increases pressure drop increases till the minimum fluidization velocity. Above the minimum fluidization velocity pressure drop remains constant and then decreases.
2. As the flow rate increases the particles moves to the further tapping's that increases pressure drop there and then pressure drop remains constant and then decreases.
3. For the lower tappings where the particles didn't reach, the pressure drop almost constant.
4. In the condition of uniform fluidization theoretically the pressure drop should be same for the conjugative tappings.

## CONCLUSION

### a. CONCLUSION:

The bed height obtained by visual observations and pressure drop by manometers.

The behaviour of particles with increasing flow rate;

- The bed remains fixed until the minimum fluidization velocity is reached.
- At the minimum fluidization velocity the lower particles just starts to move, the movement is like waves, particles goes up and comes down, net movement is zero.
- As the further increase in flow rate the movements of particles increases, the lower particles moves downward the vacant space is filled by upper particles and so on, in doing so particles leaves their position and they interact with neighbour particles, this phenomena leads to mass transfer and also heat transfer.
- On further increasing in flow rates, particles start rotational motion with wavy motion. This phenomena leads to turbulence and the better mixing.

The minimum fluidization velocity doesn't depend on the bed height.

**b. FUTURE SCOPE OF THE WORK:**

The experimental data obtained can be used in CFD analysis and for developing the empirical equations. Those can predict minimum fluidization velocity, friction factor (fanning friction factor), and pressure drop. This is also useful in study of heat and mass transfer rates in inverse fluidized beds.

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